CALIBRATING A HEC-RAS MODEL OF V-NOTCH WEIR AS INLINE STRUCTURE USING OPEN CHANNEL FLUME FLOW METHOD AND ITS APPLICATION FOR SEDIMENT TRANSPORT

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Report submitted in partial fulfilment of the requirements
for the award of the degree of
B.Eng (Hons.) of Civil Engineering

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JUNE 2015

ABSTRACT

The Hydrologic Engineering Center's River Analysis System (HEC- RAS) is a one-dimensional computer model intended to perform hydraulic calculations for a network of open channels. This model is widely available, free of cost and the most commonly used hydraulic model in the United States. Most HEC-RAS models are steady state. Unsteady flow analysis in HEC-RAS differs in many ways from the traditional steady state analysis. The main objective of this study is to compare the results of the water surface profile between HEC-RAS and the laboratory experiment. The procedure and methodology to collect the data are described. HEC-RAS will determine the water surface profile with three different discharge and manning value. The data is collected along the flume with V-notch weir is placed at fixed point. After the laboratory work is done, the computational work will obtained the result and the comparison is made. HEC-RAS's result will determine whether it is reliable to use. The prediction of sediment transport in the upstream is determined in this study. From the result and discussion the appropriate manning value is 0.010 $s/m^{1/3}$ with the value of root mean square error of 0.026358m from the upstream. The sediment transport is occur at the upstream. This research can be conclude that HEC-RAS is reliable to be used.

ABSTRAK

Hydrologic Engineering Center's River Analysis System (HEC- RAS) adalah model komputer satu dimensi yang bertujuan untuk melakukan pengiraan hidraulik untuk rangkaian saluran terbuka. Model ini boleh didapati secara meluas, bebas daripada kos dan model yang paling biasa digunakan hidraulik di Amerika Syarikat. Kebanyakan model HEC-RAS adalah keadaan mantap. Analisis aliran tak mantap dalam HEC-RAS banyak berbeza daripada analisis keadaan mantap tradisional. Objektif utama kajian ini adalah untuk membandingkan keputusan profil permukaan air di antara HEC-RAS dan eksperimen makmal. Prosedur dan kaedah untuk mengumpul data adalah seperti yang dinyatakan. HEC-RAS akan menentukan profil permukaan air dengan tiga pelepasan yang berbeza dan nilai pengendalian. Data yang dikumpul sepanjang flum dengan empang V-takuk diletakkan pada titik tetap. Selepas kerja-kerja makmal yang dilakukan, kerja-kerja pengkomputeran akan mendapat keputusan dan perbandingan itu dibuat. Hasil HEC-RAS akan menentukan sama ada ia boleh dipercayai untuk digunakan. Ramalan pengangkutan sedimen di hulu yang ditentukan dalam kajian ini. Dari hasil dan perbincangan nilai pengendalian yang sesuai adalah 0.010 $s/m^{1/3}$ dengan nilai punca min kuasa dua ralat 0.026358m dari hulu. Pengangkutan sedimen adalah berlaku di hulu. Kajian ini boleh membuat kesimpulan bahawa HEC-RAS boleh dipercayai yang akan digunakan.

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Q	discharge (m^3/s)
C_d	discharge coefficient
H	head above weir (m)
G	gravitational constant
V	velocity of flow (m/s)
g_2	gravitational acceleration
y	depth of flow (m)
y_1	depth at section 1 (m)
y_2	depth at section 2
E_1	Energy at section1
E_2	Energy at section 2
ΔE	Difference of energy between section 1 and section 2

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The Hydrologic Engineering Center's River Analysis System (HEC- RAS) is a one-dimensional computer model intended to perform hydraulic calculations for a network of open channels. This model is widely available, free of cost and the most commonly used hydraulic model in the United States. Most HEC-RAS models are steady state. Unsteady flow analysis in HEC-RAS differs in many ways from the traditional steady state analysis. The largest difference involves the ability to input a full hydrograph to analyze the response of the river system to flows that vary with time.

1.2 BACKGROUND OF STUDY

Manning value plays an important role in river analysis. It will determine the flow of the water and also the height of the water surface profile. The complex nature of the flow, standard hydraulic modeling tools, such as HEC-RAS program, could not be used accurately to determine the flow.

Laboratory experiment is carried out to compare the result of the HEC-RAS program. Prediction of sediment transport using HEC-RAS to determine whether there is transport in the inline structure.

1.3 PROBLEM STATEMENT

HEC-RAS have been used for almost 20 years and up till today HEC-RAS has difficulty in the stimulation of a steep channel or stream. Besides that, many users around the world find instability numerical unsteady flow. It is 1 dimensional hydrodynamic modeling and might not be able to work well in multi-dimensioning modeling. HEC-RAS is used to stimulate Tawau design spillway design and it is found that the results obtained in the hydraulic jump and water surface profile does not same as in manual calculation.

1.4 OBJECTIVES

The objectives of this research are:

i. To determine the water surface profile height at upstream of V-notch weir by using different.

ii. To compare the results of the water surface profile height between HEC-RAS and laboratory experimental.

iii. To obtain the appropriate manning value.

iv. To predict the sediment transport pattern in the upstream of V-notch weir.

1.5 SCOPE OF STUDY

A prototype model of an open channel is constructed in laboratory for testing purpose. The water flow through the V-notch weir model indicates the actual flow of water from the reservoir. Study scopes that have been fixed are:

i. Experiment is conducted in Hydraulic & Hydrology Laboratory of Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang.
ii. The model structure associated with a V-notch weir.
iii. Take into account of various water discharge and Manning value.

Once experiment conducted, the result will be compared with the HEC-RAS. In addition, HEC-RAS will determine the sediment transport in the upstream.

1.6 RESARCH SIGNIFICANCE

HEC-RAS is an important tool for engineers to make decisions and to stimulate the design. It is widely used by the engineers around the world for steady flow water surface profile computation, unsteady flow simulation, movable boundary sediment transport computation and water quality analysis. Besides that, this software is freely distributed which make it more people using it. The comparison between HEC-RAS and laboratory experiment is used to determine the accuracy of the manning value. HEC-RAS also provide the other utilities such as one dimensional Quasi-Unsteady Sediment Transport and to predict whether there is sediment transport in the inline structure.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will divided into two parts. First part is the open channel. It will subdivide into manning equation, hydraulic jump, flume and v-notch weir, Froude number and water surface profile. Second part is HEC-RAS. It will subdivide into Root Mean Square Error, Finite Difference Method and sediment transport.

2.2 OPEN CHANNEL

Open channel flow can be said to be as the flow of fluid (water) over the deep hollow surface (channel) with the cover of atmosphere on the top. Examples of open channels flow are river, streams, flumes, sewers, ditches and lakes etc. we can be said to be as open channel is a way for flow of fluid having pressure equal to the atmospheric pressure. While on the other hand flow under pressure is said to be as pipe flow. In example, flow of fluid through the sewer pipes.

Open-channel flow is usually categorized on the basis of steadiness. Flow is said to be steady when the velocity at any point of observation does not change with time; if it changes from time to time, flow is said to be unsteady. At every instant, if the velocity is the same at all points along the channel, flow is said to be uniform; if it is not the same, flow is said to be non-uniform. Non-uniform flow which is also steady is called as varied flow; non-uniform flow which is unsteady is called as variable flow. Flow occurs from a higher to a lower concentration by aid of gravity. Another important characteristic of open channel flow is the extreme variability encountered in cross-sectional shape and roughness, Terry W. Sturm (2001).

Figure 2.1 : An example of open channel flow eventually go to the river or ponds.

Source: (http://ceephotos.karcor.com/2011/06/23/small-open-channel-flow/)

2.2.1 Manning Equation

One the most commonly used equations governing Open Channel Flow is known as the Mannings's Equation. It was introduced by the Irish Engineer Robert Manning in 1889 as an alternative to the Chezy Equation. The Mannings equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope.

It can also be used to calculate values of other uniform open channel flow parameters such as channel slope. Manning roughness coefficient or normal depth, when the water flow rate through the open channel is known. An example set of calculations includes average flow velocity determination and water flow calculation for a given channel and flow depth. The Manning equation applies to open channel flow in natural channels as well as to man-made channels. For example, river discharge can be related to the depth of water flow and river parameters like slope, width and cross-sectional shape.

The Manning equation is:

$$Q = VA = \frac{(1)AR^{\frac{2}{3}}\sqrt{S}}{n} \tag{2.1}$$

Where:

V= velocity (m/s)

A= flow area (m^2)

R= hydraulic radius (m)

S= channel slope (m/m)

n= manning roughness coefficient

2.2.2 Manning Roughness Coefficient

The Manning roughness coefficient, n, is an experimentally determined constant. It value depends depends upon the nature of the channel and its surface. Tables giving values of *n* for different man-made and natural channel types and surfaces are available in many textbooks, handbooks and on-line. The table below gave by Chow (1959) an idea of variability to be expected in Manning's, *n.* Manning roughness coefficient values for several surfaces commonly used for open channel flow. In general smoother surfaces have lower Manning roughness coefficient values and rougher surfaces have higher Manning roughness coefficient values

.

Table 2.1 : Manning Roughness Coefficient

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120

Table 2.2 : Manning Roughness Coefficient (*continue*)

5. same as 4. with flood stage reaching branches	0.100	0.120	0.160
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.010	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood			
1. planed, untreated	0.010	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015
3. unplanned	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018
5. lined with roofing paper	0.010	0.014	0.017
c. Concrete			

Table 2.3 : Manning Roughness Coefficient (*continue)*

1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel on bottom	0.015	0.017	0.020
4. unfinished	0.014	0.017	0.020
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025
7. on good excavated rock	0.017	0.020	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.020
2. random stone in mortar	0.017	0.020	0.024
3. cement rubble masonry, plastered	0.016	0.020	0.024
4. cement rubble masonry	0.020	0.025	0.030
5. dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.020	0.025
2. random stone mortar	0.020	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. glazed	0.011	0.013	0.015
2. in cement mortar	0.012	0.015	0.018
g. Masonry			
1. cemented rubble	0.017	0.025	0.030
2. dry rubble	0.023	0.032	0.035
h. Dressed ashlar/stone paving	0.013	0.015	0.017
i. Asphalt			
1. smooth	0.013	0.013	
2. rough	0.016	0.016	
j. Vegetal lining	0.030		0.500

Source:
(http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm)

2.2.3 Flume And V-Notch Weir

Flume is an artificial channel conveying water. Many flumes took the form of wooden troughs elevated on trestles, often following the natural contours of the land. Originating as a part of a mill race, they were later used in the transportation of logs in the logging industry. They were also extensively used in hydraulic mining and working placer deposits for gold, tin and other heavy minerals. Flumes are not to be confused with aqueducts, which are built with the goal of transporting the water, whereas a flume would use the flowing water to transport other materials.

The v-notch weir is one type of sharp crested weir. Utilizing the same approach as for the derivation of the head-discharge relationship for rectangular sharp-crested weir. It can be shown that the head-discharge relationship for a V-notch weir as

$$Q = Cd\ \frac{8}{15}\sqrt{2g}\tan\frac{\theta}{2}H^{5/2} \tag{2.2}$$

Where;

Q= discharge (m^3/s)

C_d= discharge coefficient

H = head above weir (m)

g= gravitational constant (m^2/s)

The weir crest is the top of the weir. For a v notch weir it is the point of the notch, which is the lowest point of the weir opening.. The drawdown is the decrease in water level going over the weir due to the acceleration of the water. The head over the weir is shown as H in the diagram; the height of the weir crest is shown as P; and the open channel flow rate or discharge is shown as Q.

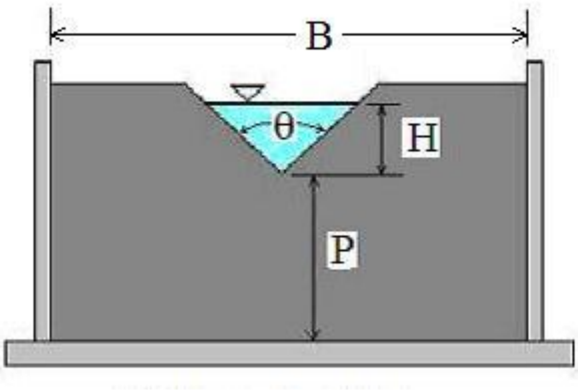

Figure 2.2: V-notch crested weir

Source : (http://www.engineeringexcelspreadsheets.com/2011/04/v-notch-weir-calculator-excel-spreadsheet/)

2.2.4 Hydraulic Jump

An Italian engineer, Bidone (1818) found that hydraulic jump is the phenomenon when supercritical stream meets a subcritical stream of sufficient depth. The supercritical stream jumps up to meet the alternate depth. The hydraulic jump serves as an energy dissipater to dissipate the excess energy of flowing water downstream of hydraulic structure.

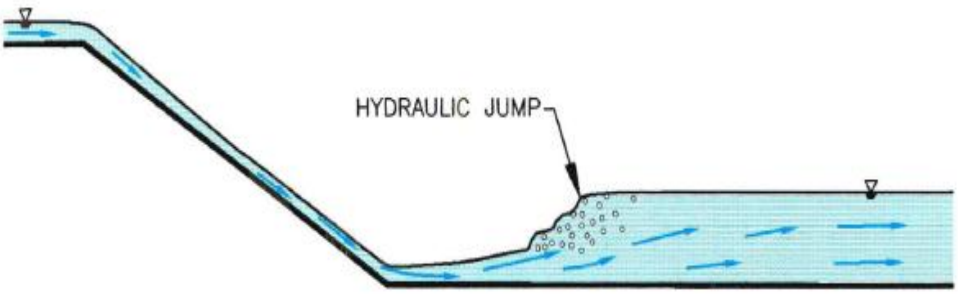

Figure 2.3: The phenomenon hydraulic jump

Source : (krcproject.groups.et.byu.net)

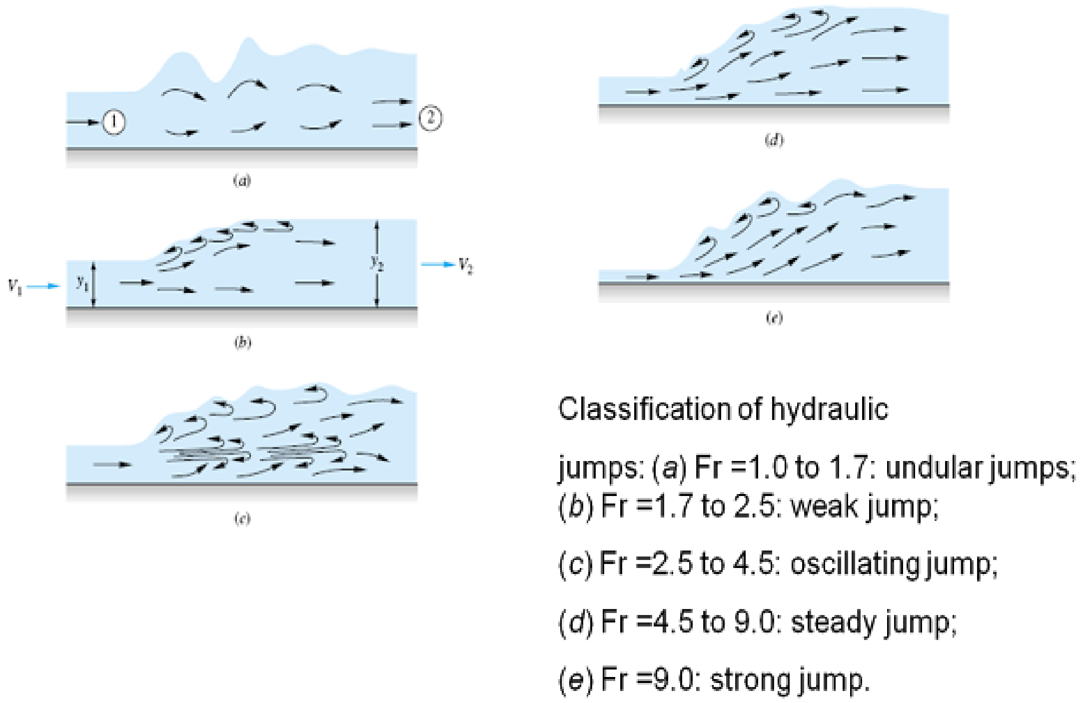

Figure 2.4: Appearance of hydraulic jump for different Froude number ranges

Source : (http://optimist4u.blogspot.com/2011/04/hydraulic-jump-and-its-practical.html , 2011)

2.2.5 Froude Number

Froude Number is a dimensionless number define as the ratio of a characteristic velocity to gravitational velocity. Named after William Froude, the Froude number is based on the speed-length ratio as below:

$$Fr = \frac{v}{\sqrt{g y_c}} \tag{2.3}$$

where;

v = velocity of flow (m/s)

g = gravitational acceleration(m2/s)

y = depth of flow (m)

Table 2.4: Classification of hydraulic jumps according to Froude Number

Fr1 <1.0	Jump impossible, violates second law of thermodynamics**.**
Fr1=1.0 to 1.7	Standing-wave, or undular, jump about 4y2 long; low dissipation, less than 5 percent.
Fr1=1.7 to 2.5	Smooth surface rise with small rollers, known as a weak jump; dissipation 5 to 15 percent.
Fr1=2.5 to 4.5	Unstable, oscillating jump; each irregular pulsation creates a large wave which can travel downstream for miles, damaging earth banks and other structures. Not recommended for design conditions. Dissipation 15 to 45 percent.
Fr1=4.5 to 9.0	Stable, well-balanced, steady jump; best performance and action, insensitive to downstream conditions. Best design range. Dissipation 45 to 70 percent.
Fr1>9.0	Rough, somewhat intermittent strong jump, but good performance. Dissipation 70 to 85 percent.

When Froude number approaches $\frac{V}{\sqrt{gy}}$:

$$\frac{y2}{y1} = \frac{1}{2}\left(-1 + \sqrt{1 + 8F^2}\right) \tag{2.4}$$

Where as energy loss can be find by

$$\Delta E = \frac{(y_2 - y_1)^3}{4y_1y_2} \tag{2.5}$$

Where:

y_2= depth at section 2 (m)

y_1= depth at section 1 (m)

Fr_1= Froude number at section 1

E_1= Energy at section1 (m)

E_2= Energy at section 2 (m)

ΔE = Difference of energy between section 1 and section 2 (m)

2.2.6 Water Surface Profile

The water surface profile is a measure the depth flow longitudinally. It is classified between actual water depth (y), normal depth (y_n) and critical depth (y_c). Normal depth is the depth of flow that would occur if the flow was uniform and steady, and is usually predicted using the Manning's Equation. Critical depth is defined as the depth of flow where energy is at a minimum for a particular discharge.

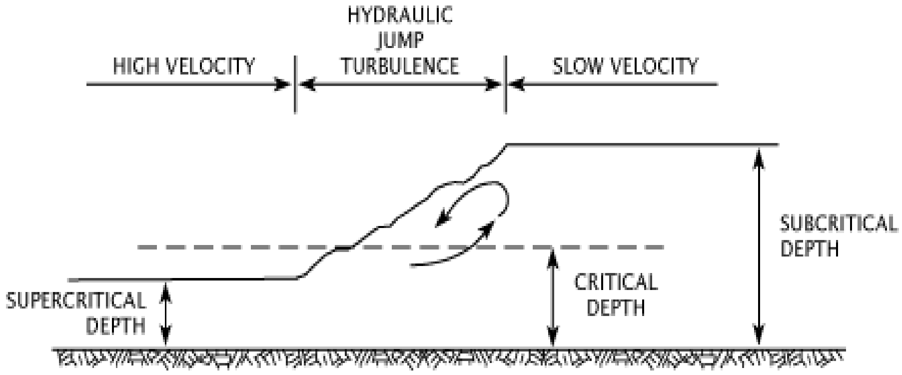

Figure 2.5: Water surface in an open channel when water flowing at high velocity

Source : (http://www.owp.csus.edu/glossary/hydraulic-jump.php)

Table 2.5: Description of hydraulic curve

Type 1 curve	Depth is greater than y_c and y_n flow is subcritical.
Type 2 curve	Depth is between y_c and y_n, flow can be either subcritical or supercritical.
Type 3 curve	Depth is less than both $y_c$and y_n, flow is supercritical.